ASPECTS OF THE LIFE HISTORY OF THE TWO-SPINED BLACKFISH *GADOPSIS BISPINOSUS* IN KING PARROT CREEK, VICTORIA

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The population of the two-spined blackfish, *Gadopsis bispinosus*, in King Parrot Creek, Victoria consisted mainly of individuals with total lengths from 30 to 190 mm. Individuals longer than 210 mm comprised less than 2 % of the total sample of 1054 fish. Juvenile recruitment occurred in summer. Length–weight relationships indicate that females are slightly heavier than males. The spawning season, as inferred from ovarian development, was from October to December when water temperatures increased rapidly from the winter minimum. The seasonal nature of ovarian development was strongly influenced by total length, with larger females developing gravid ovaries earlier in the spawning season. Total length and fecundity were linearly related. The diet was dominated by various aquatic benthic invertebrate larvae and terrestrial insects. A comparison of the life histories of the two described species of *Gadopsis* shows them to be very similar.

APART FROM its description (Sanger 1984), a discussion on the use of artificial habitat to increase population size (Koehn 1987) and recent distributional information (Koehn 1990, Lintermans & Rutzou 1990), nothing has been published on the biology of the two-spined blackfish, *Gadopsis bispinosus*. Jackson (1978a, b) reported on several aspects of the biology of the related species *G. marmoratus* Richardson, including habitat preference, feeding, spawning and early life history. Collection of such information, which may be referred to as life history analysis, is of increasing importance given the recent level of interest in formal lists of the conservation status of Australian freshwater fish (Cadwallader et al. 1984, Harris 1987, Koehn & Morrison 1990) and in the management of wild populations of native fish for conservation purposes. In combination with detailed distributional data, life history analysis can provide a firm biological basis for decisions on both conservation status and management.

The life history of *G. bispinosus* is of interest not only because of the relatively recent discovery of the species, its somewhat restricted distribution and apparent abundance in streams inhabited by salmonids (Koehn 1990), but also because there is the opportunity for a comparison with the work of Jackson (1978a, b). Such a comparative approach may reveal factors of general relevance to management guidelines for *Gadopsis* species.

In order to examine the life history of *G. bispinosus*, a population was investigated in the upper reaches of King Parrot Creek (a tributary of the Goulburn River in the Murray River system), approximately 8 km downstream from Kinglake West, Victoria (37°52′S, 145°23′E). King Parrot Creek is typical of the streams in which this species is found: cool and clear with a cobble substrate.

MATERIALS AND METHODS

Physical data on mean monthly discharge and water temperature in King Parrot Creek were obtained from Rural Water Commission records from the Flowerdale water quality gauging station, situated about 10 km downstream of the study site. Samples of fish were collected with a portable DC electroshocker at approximately monthly intervals over a period of two years. They were killed in a solution of benzocaine and preserved in 4% formaldehyde.

Total length (TL) was measured to the nearest mm and total wet weight to the nearest 0.1 g. Fish were sexed by macroscopic gonadal examination. Males had a single, small, nodular, pinkish testis; females had a single, anteriorly bilobed, whitish to yellow ovary, within which developing oocytes could be seen. Juveniles had little or no gonadal tissue present; if present it was not obviously testicular or ovarian. Ovaries were dissected from preserved specimens, blotted dry, and weighed to the nearest 0.001 g. The Gonadosomatic Index (GSI) was calculated by expressing ovary weight as a percentage of total body weight. Mean egg diameter (to the nearest 0.1 mm) was determined microscopically with the aid of a graduated scale. If mean egg diameter was at least 2.0 mm all eggs were dissected from the ovary and counted. Such ovaries were arbitrarily considered to be gravid. The stomach contents of several samples were examined under a stereo microscope. Individual food items were assigned to food categories broadly matching those used by Jackson (1978b), except that all aquatic Coleoptera were combined in a single category instead of two, and three new categories were used for food items not covered by Jackson's categories. These new categories are Decapoda for freshwater crayfish and *Paratya* sp., Isopoda for the semi-aquatic oniscoids, and galaxiids for the native fish *Galaxias olidus*. The composition of the diet was analysed by the occurrence, number and dominance methods as described by Hynes (1950). For comparison with the work of Jackson (1978b), the rank method of Pollard (1973) was also used. Although it is recognised that these methods of analysis are inherently biased in one way or another, use of several methods concurrently should reveal important components of the diet of *G. bispinosus*. Statistical analyses were performed with BMDP statistical software (Dixon 1983).

RESULTS

All samples were collected from a 100 m long section of the creek chosen because of its accessibility. The river bed in this section comprised stones varying in size from coarse gravel providing little in the way of cover, to cobbles providing adequate cover for fish. Additional instream cover was provided by several fallen logs and branches, and undercut banks in riffle regions and on the outer bank of bends. *Gadopsis bispinosus* was common in all habitats where adequate cover was present. The species was encountered infrequently in open water or over more homogeneous substrates without cover. The two exotic species *Salmo trutta* and *Perca fluviatilis* and the native species *Galaxias olidus* were also collected from this section of King Parrot Creek during the study. Of these species, only *S. trutta* was common.

Mean monthly discharge varied markedly over the two year sampling period (Fig. 1); however, variation followed a regular pattern of high flows (more than 100 $ML.day^{-1}$) in late winter and early spring, and low flows (less than 20 $ML.day^{-1}$) in late summer and autumn. Water temperature ranged between 8.5°C in mid winter and 24.5°C in mid summer (Fig. 1).

Length-frequency data for the entire sample ($n = 1054$) and for seasonal samples are given in Fig. 2. Mean TL for the entire sample (Fig. 2A) is 111 mm (range = 20 to 257 mm). The 40 mm (30–49 mm) to 180 mm (170–189 mm) size classes comprise more than 90% of the total sample; the 220, 240 and 260 mm size classes comprise less than 2%. Seasonal variation in maximal and mean TL is small (Fig 2B). The appearance of the smallest size class (20 mm; 10–29mm) in the summers of 1981 and 1982 indicates that recruitment of juveniles occurred in this period. In the autumn of both these years a strong 0+ cohort can be seen as the first peak on the histograms.

The relationship between total length and total weight for the entire sample, and for males and females separately, is indicated in Table 1. Females were slightly heavier than males (ANCOVA; $p < 0.01$).

Most individuals less than 100 mm TL were classified as juveniles ($n = 385$), with 57 females and 19 males comprising the remainder. The difference between the number of males and females in these small fish is due to the fact that females are easier to recognise than males; female gonads are larger than those of males, so that females were easier to distinguish from juveniles than were males. The sex ratio of fish greater than 100 mm TL ($n = 288$ males, 306 females) did not differ significantly from 1:1 (Chi square = 0.545, $p < 0.75$).

Females with gravid ovaries were found between September and December in 1980, and between October and December in 1981 (Table 2). The values of ΔN in Table 2 show how many females in each monthly sample were larger than the largest gravid female in that sample. These values increased during the spawning period in both years. Thus, early in the spawning season the largest gravid females tended to be the largest females in the sample. As the spawning season progressed, the larger females possessed very small developing ovaries (GSI < 1.1) and smaller gravid females were present (GSI > 9.4). In the January samples, all adult females had ovaries in the early stages of development (GSI values normally < 1). Water temperature rose rapidly from about 12°C to 17°C between October and November in 1980, and between November and December in 1981. Thus, it

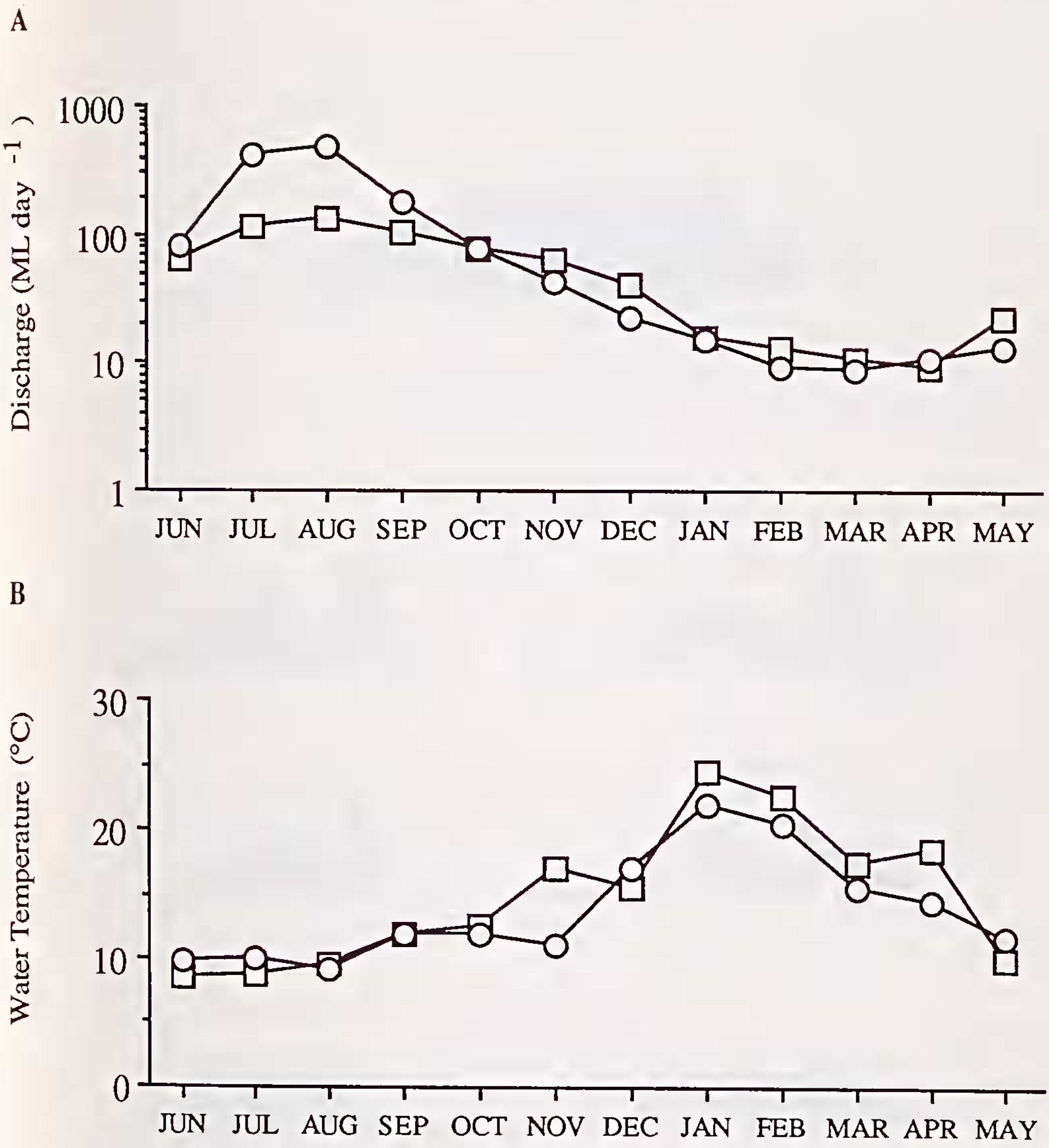

Fig. 1. Environmental characteristics of King Parrot Creek between June 1980 and May 1982. A, mean monthly discharge in $ML.day^{-1}$. B, water temperature in °C. Open squares 1980–81; open circles 1981–82.

	Regression equation	n	r	p
Total sample	Log_{10} W = 2.856 Log_{10} TL – 4.805	1054	0.994	<0.001
Females	Log_{10} W = 2.757 Log_{10} TL – 4.589	363	0.990	<0.001
Males	Log_{10} W = 2.751 Log_{10} TL – 4.587	307	0.986	<0.001

Table 1. Relationship (linear regression) between total length (TL) and weight (W) of *Gadopsis bispinosus* in King Parrot Creek; n = sample size, r = correlation coefficient, p = probability value for r.

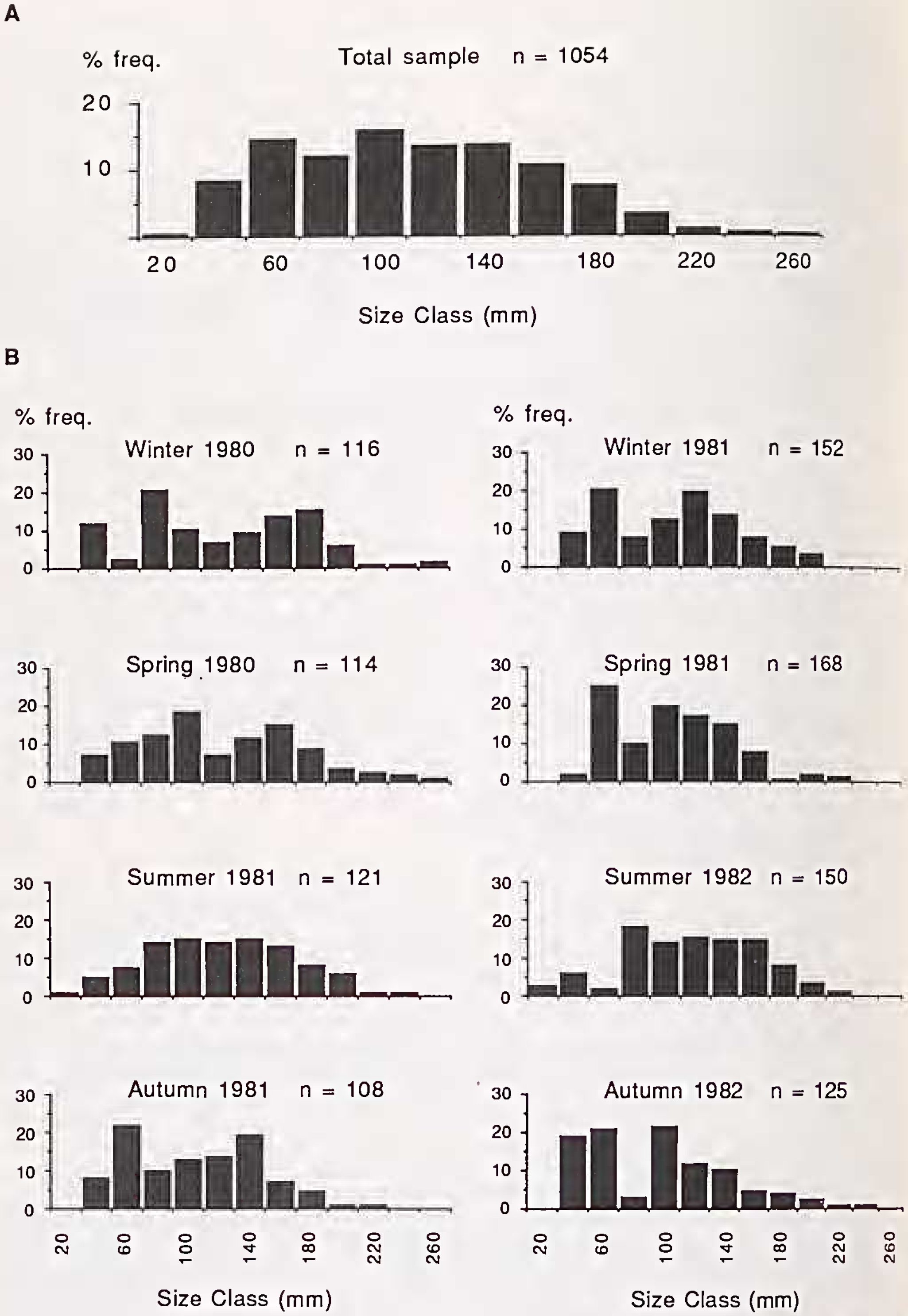

Fig. 2. Length-frequency histograms for (A) the total sample and (B) seasonal samples of *Gadopsis bispinosus* in King Parrot Creek.

Month	Water temp. (°C)	Total sample N	Total sample Mean GSI	Largest female TL	Largest female GSI (mm)	Largest gravid female TL	Largest gravid female GSI (mm)	ΔN
September 80	11.9	15	2.22	198	5.77	198	5.77	0
October 80	12.6	11	5.12	207	11.84	207	11.84	0
November 80	17.0	9	4.90	230	0.95	158	10.48	4
December 80	15.5	17	1.36	242	0.04	116	15.40	10
January 81	24.5	22	0.33	242	0.38	no gravid females		–
September 81	11.9	17	1.05	196	2.45	no gravid females		–
October 81	11.9	13	1.12	177	9.64	177	9.64	0
November 81	11.0	23	3.20	194	0.01	152	9.46	2
December 81	17.0	18	6.62	178	1.02	117	16.3	7
January 82	22.0	13	0.38	184	0.42	no gravid females		–

Table 2. Seasonal variation in GSI values and length of gravid females; N = number of females in monthly sample, ΔN = number of females larger than largest gravid female.

Category	Occurrence	Number	Dominance	Rank
Trichoptera	76.0	15.9	24.4	21.6
Diptera	67.6	31.1	8.3	15.3
Ephemeroptera	81.1	33.3	29.4	24.5
Plecoptera	33.5	6.9	3.2	8.7
Coleoptera	27.3	2.8	3.0	6.9
Hemiptera	4.7	0.4	0.9	0.9
Odonata	4.0	0.3	1.5	1.2
Megaloptera	1.1	<0.1	1.2	0.3
Amphipoda	14.6	3.1	3.0	3.8
Decapoda	6.5	0.4	3.4	1.8
Isopoda	1.5	0.1	0.4	0.3
Oligochaeta	4.7	0.3	3.1	1.5
Arachnida	1.1	<0.1	0.0	0.3
Terrestrial	28.4	4.4	15.7	8.7
Fish eggs	1.1	0.5	0.8	0.5
Galaxias olidus	0.4	<0.1	0.4	0.2
Miscellaneous	11.6	0.3	1.9	3.2

Table 3. Stomach contents of *Gadopsis bispinosus* from King Parrot Creek; n = 275. Occurrence = percentage of stomachs in which each category occurs; number = percentage contribution of each category to total number of food items; dominance = percentage of stomachs in which each category dominated volumetrically; rank = percentage composition of diet by rank method.

appears that the spawning season extends over several months from about October to December, that large females spawn earlier than small females, and that the onset of spawning coincides with an increase in water temperature in spring.

The number of eggs in gravid ovaries ranged between 84 (fish TL = 121 mm) and 350 (fish TL = 207 mm). The relationship between total length and fecundity is described equally well by the relationships:

$$\text{Fecundity} = 2.50\ \text{TL} - 205;\ r^2 = 0.74;\ p < 0.001;$$

and

$$\text{Log}_{10}\ \text{Fecundity} = 2.16\ \text{Log}_{10}\ \text{TL} - 2.50;\ r^2 = 0.72;\ p < 0.001$$

The exponential relationship is probably more appropriate because the number of eggs in an ovary is governed more by the volume of the ovary (a cubic measure) than by its length. Nevertheless, the significance of the two correlations is identical.

Table 3 summarises the results of the analysis of the stomach contents of 275 fish taken from 14 samples spaced at approximately two-monthly intervals over the sample period. The dietary importance of several groups of benthic insect larvae is evident from the table, with ephemeropteran, trichopteran and dipteran nymphs and pupae predominating in the diet assessed by all four methods of analysis. Terrestrial arthropods and the aquatic groups Plecoptera, Coleoptera, and Amphipoda were also important in the diet. The method-dependent differences between the scores for each category reflect the biases inherent in the methods. For example, whereas dipteran larvae occurred frequently and were often numerous, they were usually small and did not dominate many guts volumetrically. Thus, dipteran larvae scored higher values in the occurrence and number methods than in the dominance and rank methods.

Fish eggs, almost certainly eggs of *G. bispinosus*, were found in the diet of a few fish in December 1981 and 1982, supporting the suggestion that spawning had taken place at this time.

The major aquatic groups, i.e. Ephemeroptera, Trichoptera, Diptera, Plecoptera and Coleoptera, were relatively important in all monthly samples (Table 4). Terrestrial food was more important in the spring and summer months, perhaps reflecting a greater availability during this period.

DISCUSSION

Gadopsis bispinosus is the most abundant species of fish in the upper reaches of King Parrot Creek. Koehn (1987) found that it was also the most abundant species of fish in the upper reaches of the Ovens River, Victoria, and has shown experimentally that an increase in the amount of instream cover led to an increase in abundance of the species in that stream. It appears likely, therefore, that *G. bispinosus* would be abundant in most north-eastern Victorian streams with abundant instream cover (especially accumulations of cobbles and fallen timber) and relatively cool, clear water.

The length-frequency distributions confirm that, at least in King Parrot Creek, *G. bispinosus* is a small to medium-sized species (observed maximum TL 257 mm). The causes of adult mortality are unknown, apart from predation by *Salmo trutta* (Sanger 1984). It has been suggested that there is a correlation between the presence of *S. trutta* and a decline in the abundance and diversity of the native fish fauna in

Sample date	n	Ephemeroptera	Trichoptera	Diptera	Plecoptera	Coleoptera	Hemiptera	Odonata	Amphipoda	Decapoda	Isopoda	Annelida	Terrestrial	Fish eggs	*G. olidus*	Miscellaneous
24.5.80	12	22.9	11.1	21.5	11.7	3.9	–	5.6	13.6	2.3	–	–	3.2	-	-	4.2
21.8.80	18	16.0	10.3	19.0	9.5	9.9	2.7	1.3	12.3	4.2	0.5	–	5.7	-	-	7.1
24.9.80	12	24.2	9.0	27.0	2.6	6.6	–	–	8.8	–	–	2.8	15.6	-	-	3.3
20.10.80	13	22.7	12.5	21.0	20.0	5.2	–	–	–	–	–	4.5	12.7	-	-	1.4
22.12.80	20	22.8	15.1	25.0	4.8	7.8	–	–	–	1.8	–	–	7.5	5.1	-	10.2
20.2.81	18	20.0	17.4	27.9	–	9.6	–	2.1	–	–	–	–	19.8	-	-	3.2
22.4.81	23	24.0	27.6	19.4	3.5	12.1	–	–	–	1.4	–	–	4.9	–	-	7.1
19.5.81	23	18.9	22.9	25.6	11.9	2.1	–	1.9	4.9	1.6	–	–	2.6	–	-	7.7
21.6.81	21	18.4	13.6	29.4	14.0	5.4	1.8	0.6	1.8	3.2	–	1.8	7.2	-	-	2.8
16.9.81	20	23.8	11.8	28.6	16.3	4.5	1.4	–	–	–	1.4	2.1	4.1	–	2.1	4.1
24.12.81	17	24.9	16.6	25.3	8.1	9.0	0.6	–	–	2.3	–	3.7	6.1	2.3	-	1.5
22.2.82	34	15.1	10.3	16.7	7.3	8.5	2.4	3.8	8.9	4.6	–	3.4	15.4	-	-	3.8
23.3.82	26	20.1	18.2	32.2	1.4	6.0	2.9	0.6	–	1.8	1.2	1.6	12.5	-	-	2.1
17.5.82	18	27.9	17.3	25.3	10.2	5.3	1.8	1.2	2.3	2.3	1.6	–	4.0	-	-	0.8
Total % rank	275	21.6	15.3	24.5	8.7	6.9	0.9	1.2	3.8	1.8	0.3	1.5	8.7	0.5	0.2	3.2

Table 4. Seasonal comparison of the diet of *Gadopsis bispinosus* from King Parrot Creek, analysed by the rank method.

Australian streams (Tilzey 1976, Jackson & Williams 1980). The presence of *S. trutta* does not appear to affect the abundance of *G. bispinosus* in the present study. Indeed, the recent study by Koehn (1987) suggests that the amount of instream cover is a more serious limiting factor. Similarly, *G. marmoratus* has been found to cope adequately with the competitive pressure of coexistence with *S. trutta* in some Victorian streams (Jackson 1978b, Jackson & Williams 1980), and the abundance of *G. marmoratus* in some Victorian and Tasmanian streams has been shown to be correlated more closely with instream cover and low flows than with any other habitat attributes (Cadwallader 1979, Koehn 1986, Davies 1989).

The timing of recruitment of *G. bispinosus* appears to be similar to that of *G. marmoratus* found by Jackson (1978a) and Koehn (unpublished data) in some Victorian streams. In both those studies spawning activity was found between mid-November and mid-December. Jackson (1978) concluded from aquarium observations that the time from spawning to active feeding was about eight weeks, and suggested that recruitment should have occurred in January and February in the McKenzie River in 1976. Recruits were first detected in the King Parrot Creek population of *G. bispinosus* in February 1981 (mean TL 39.9 mm) and January 1982 (mean TL 27.1 mm). The water temperatures in King Parrot Creek from November to February are within the range reported by Jackson (1978a) for the McKenzie River, and by Koehn (unpublished data) for Armstrong Creek. Although in the present study the spawning period of *G. bispinosus* has been determined indirectly from ovarian condition and from predation on eggs, it is similar to that reported for *G. marmoratus* and shows a similar association with increasing water temperatures. The maximum diameter of ovarian eggs in *G. bispinosus* (3.5–4.0 mm) and of fertilized eggs in *G. marmoratus*, and the correlation of fecundity with total length are also similar (Jackson 1978a, Koehn unpublished data). The relationship between total length and month of maturity has not been reported previously for species of *Gadopsis*.

At the taxonomic level employed in the present study, the diet of *G. bispinosus* is very similar to that of *G. marmoratus* in the Aberfeldy River, as described by Jackson (1978b). Terrestrial insects were more important than dipteran larvae in the diet of *G. marmoratus* in the Aberfeldy River, but the influence of different sample dates, the size range of fish used and the availability of the different prey types could all have influenced this result. The presence of freshwater crayfish, a galaxiid fish and fish eggs also distinguish the diet of *G. bispinosus* from that of *G. marmoratus* in the Aberfeldy River, although these items do not comprise a major part of the diet of *G. bispinosus*. The seasonal composition of the diet of *G. bispinosus* was relatively stable, no distinct seasonal peaks in rank values for any food category being evident in the data. The seasonal composition of the diet of *G. marmoratus* in the Aberfeldy River was also relatively stable.

The concurrence of life history characteristics of *G. bispinosus* and *G. marmoratus* should enable the formulation of overall guidelines for the management of wild populations of *Gadopsis* species. The importance of instream cover to both species has already been demonstrated (Jackson 1978a, b; Koehn 1986, 1987; Davies 1989). Other features which appear to be important are a spring increase in water temperature which correlates with the onset of spawning, and the heavy reliance on benthic invertebrates in the diet of both species. Environmental degradation, including an artificial lowering of spring and early summer water temperatures through release of cold impoundment water, a decrease in the amount of instream cover either from de-snagging or siltation, and disruption of the benthic invertebrate fauna through substrate disturbance or the introduction of toxins into streams, could thus be expected to have a detrimental effect on stream populations of *Gadopsis* species.

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